Antiproton Acceptance

Steve Werkema

DOE Review

July 21, 2003

Scope

Two Projects:

1. AP2 Beamline and Debuncher Acceptance Improvements

   Project Leader: Keith Gollwitzer

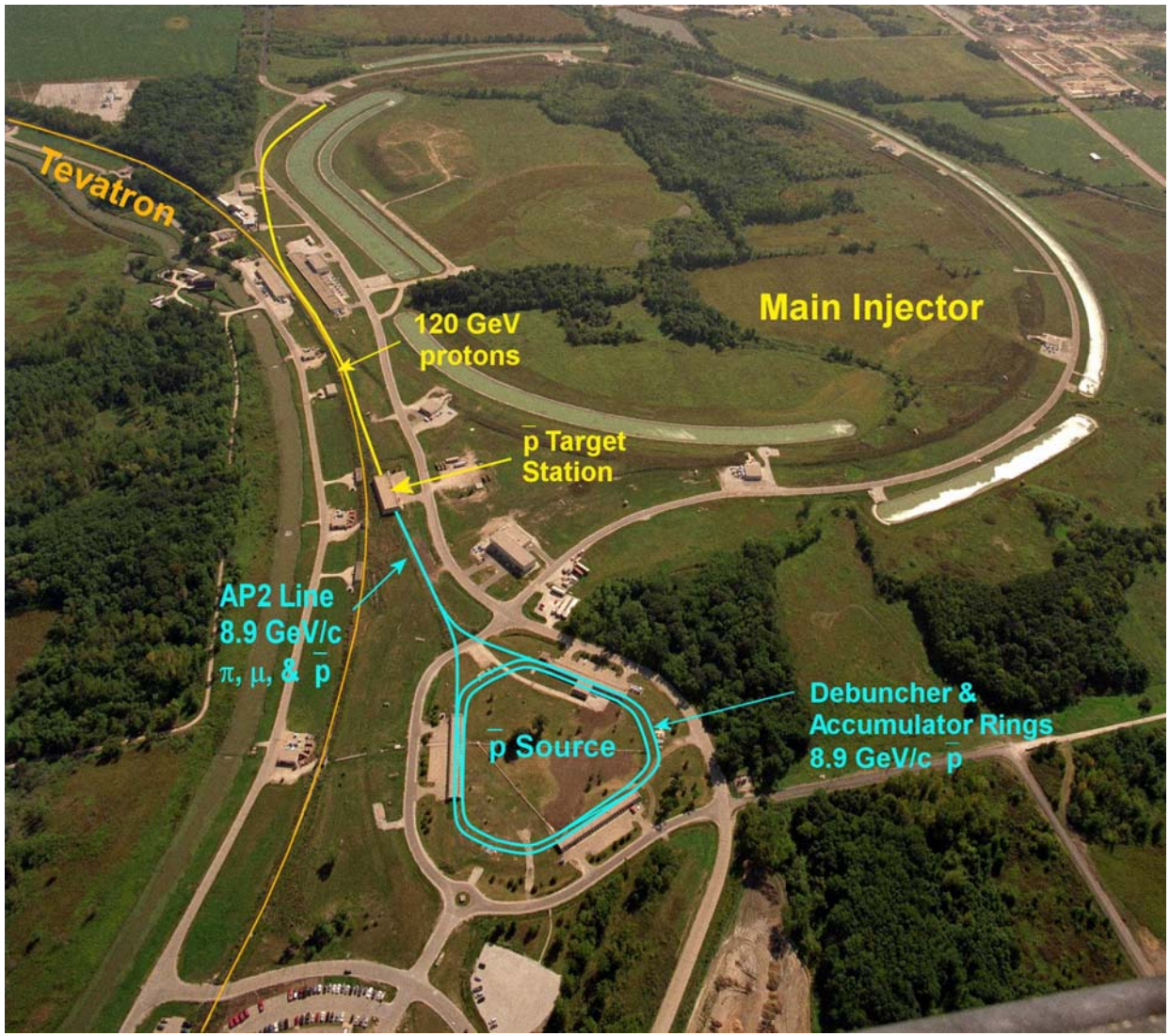
- High Gradient Lithium Lens Upgrades

  Project Leader: Jim Morgan

Layout

Layout of Antiproton Acceptance projects:

- Target station – downstream of target
- AP2 beamline
- Debuncher ring



WBS Overview

WBS	Task	In Charge	Labor Est ($K)	Labor Cont	M&S Est ($K)	M&S Cont	Start
1.3.2	**Pbar Acceptance**	**Steve Werkema**	**2,247**	**66%**	**1,871**	**72%**	**1/1/03**
1.3.2.1	Lithium Lens Upgrades	Jim Morgan	575	71%	463	73%	4/1/03
1.3.2.1.1	Modifications to existing lens	Pat Hurh	76	40%	62	40%	7/1/03
1.3.2.1.2	New lens design	Pat Hurh	151	50%	126	45%	4/1/03
1.3.2.1.3	General lens R&D	Pat Hurh	110	58%	75	75%	4/1/03
1.3.2.1.5	Fabricate new lenses	Pat Hurh	239	100%	200	100%	4/12/05
1.3.2.2	AP2 and Debuncher Acceptance	Keith Gollwitzer	1,671	64%	1,408	72%	1/1/03
1.3.2.2.1	Assemble documentation & drawings	Dave VanderMeul	109	20%	0	0%	1/1/03
1.3.2.2.2	Optical Survey & Alignment	Keith Gollwitzer	27	40%	0	0%	8/25/03
1.3.2.2.3	Instrumentation	Keith Gollwitzer	272	70%	213	83%	1/1/03
1.3.2.2.4	Beam based alignment (BBA)	Keith Gollwitzer	379	60%	0	0%	10/1/03
1.3.2.2.5	Redesign/modify/rebuild/relocate elements	Keith Gollwitzer	727	74%	973	80%	1/1/04
1.3.2.2.6	Orbit Control	Keith Gollwitzer	53	32%	202	20%	8/25/03
1.3.2.2.7	Increase admittance of the Debuncher injection	Ina Reichel (LBNL	0	0%	20	60%	4/1/03
1.3.2.2.8	Develop model of AP2 and Debuncher lattice	Keith Gollwitzer	39	43%	0	0%	1/1/03
1.3.2.2.9	AP2 and Debuncher Acceptance Beam Studie	Keith Gollwitzer	64	60%	0	0%	4/1/03
1.3.2.2.10	Initial AP2&DB Improvements Complete (Miles	Keith Gollwitzer	0	0%	0	0%	8/12/04

AP2 & Debuncher Acceptance – Admittance Measurement

Measurements of AP2 & Debuncher vertical admittance

Figures at the right plot various measurements of beam intensity as a function of vertical scraper position.

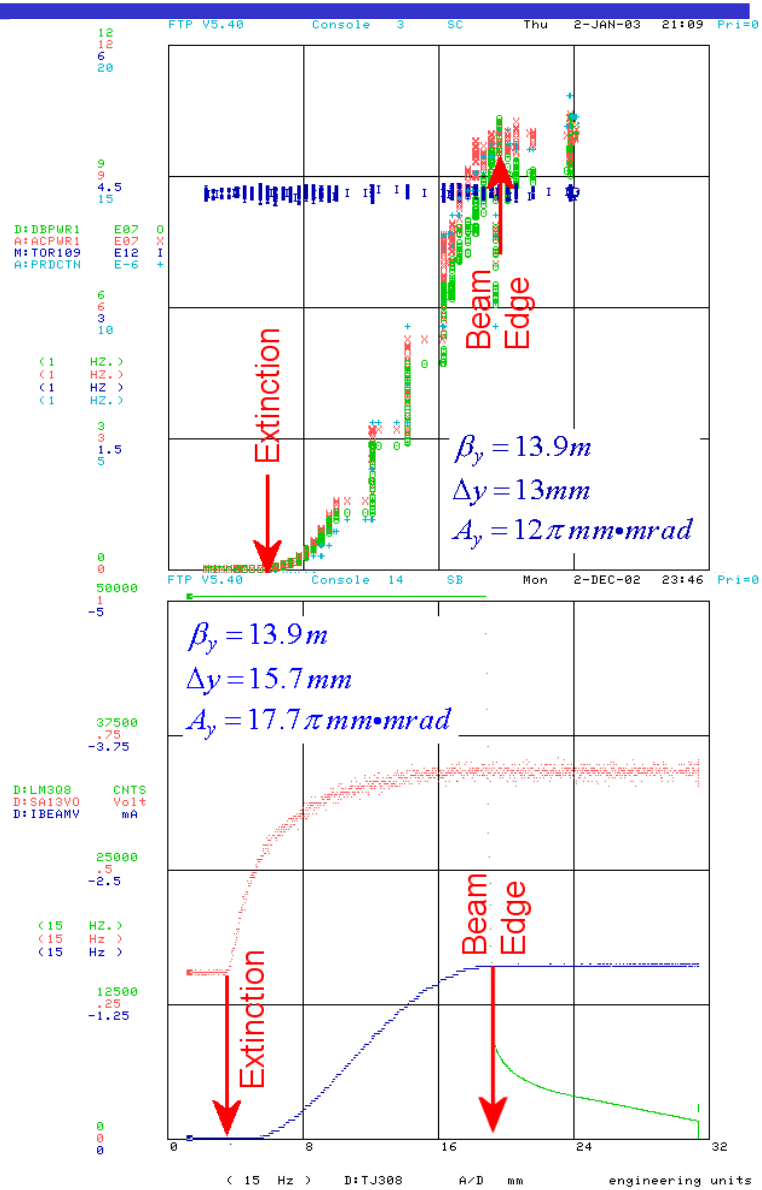
Top scan – AP2 + Debuncher

- Performed *while stacking*
- Beam intensity measured by integrating longitudinal schottky power spectral density (linear scale)
- Very noisy

Bottom scan – Debuncher Only

- Heated *reverse protons* in the Debuncher
- Loss monitor used to detect beam edge
- Schottky power on log scale (red trace

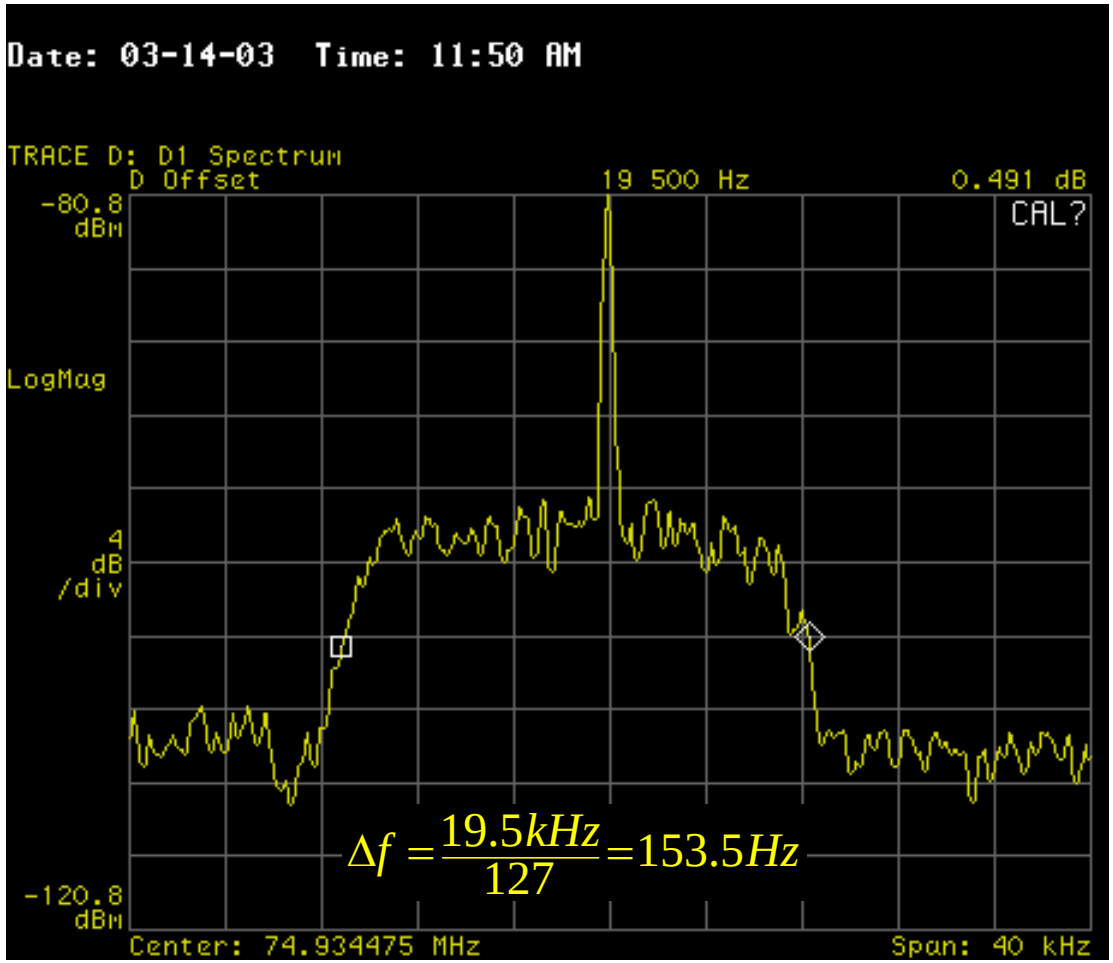
AP2 + Debuncher admittance is less than that of the Debuncher alone



AP2 & Debuncher Acceptance – Momentum Acceptance

Longitudinal Schottky profile of $\bar{p}$'s filling the momentum aperture of the Debuncher.

Bunch rotation and stochastic cooling are off.



$$\frac{\Delta p}{p} = \frac{1}{\eta}\frac{\Delta f}{f}$$
$$= \frac{1}{0.006} \cdot \frac{153.5Hz}{590035Hz}$$
$$= 4.3\%$$

AP2 & Debuncher Acceptance -- Parameters

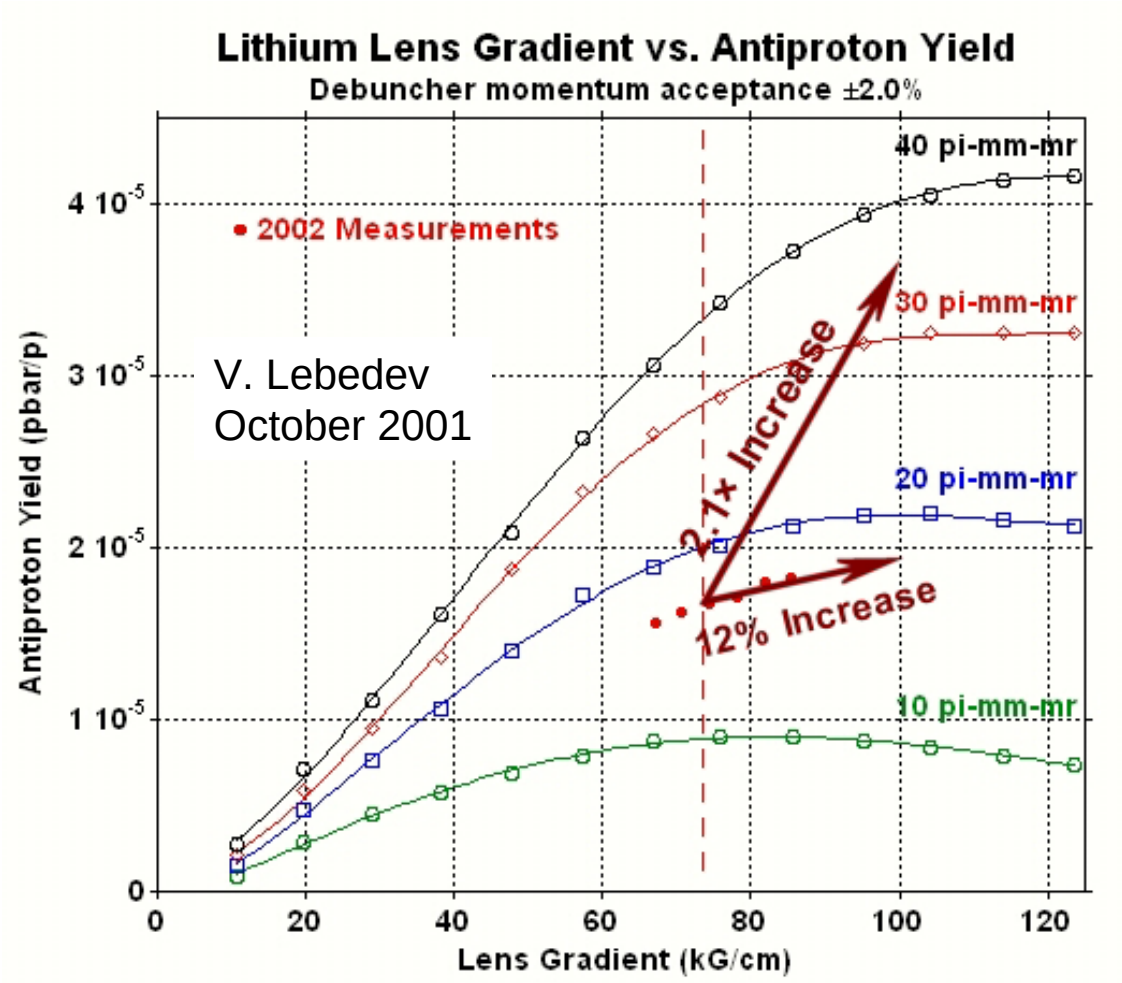
	Recent Measurements	Physical Aperture	TeV I Design Admittance	Goal
Horizontal (mm-mrad)	20 ± 4 π	40 π†	20 π	35 π
Vertical (mm-mrad)	12 ± 4 π	40 π †	20 π	35 π
Momentum	±2.25%	±2.25%	±2.00%	±2.25%

† There are several locations where the physical aperture is known to be less than the admittance indicated in this table (e.g. Band 4 cooling pickups and kickers, Debuncher quadrupole D4Q4, DRF2 and DRF3 cavities).

Motivation

Increase the number of antiprotons collected from the target by:

- increasing the gradient of the collection lens
- increasing the admittance of the AP2 beamline and the Debuncher



AP2 & Debuncher Acceptance -- Plan

- Identify Limiting Apertures:
  - Assemble Documentation and Drawings (FNAL Tech. Div.) (WBS 1.3.2.2.1)
  - Optical Survey and Alignment (WBS 1.3.2.2.2)
  - Beam Studies (WBS 1.3.2.2.9.2)
  - Improve AP2 and Debuncher Lattice models (WBS 1.3.2.2.8)
    - Required for Beam Based alignment
    - Dynamical aperture issues
- Mitigate aperture restrictions
  - Redesign/modify/rebuild/relocate beamline elements (WBS 1.3.2.2.5)
  - Increase admittance of Debuncher Injection channel (LBNL) (WBS 1.3.2.2.7)
- Implement Beam Based Alignment
  - Instrumentation upgrades (WBS 1.3.2.2.3) New
    - AP2 BPMs
    - Debuncher BPMs
  - Orbit control (WBS 1.3.2.2.6) New
    - Install additional dipole trims in AP2
    - Motorized quad stands in the Debuncher
  - Beam Based Alignment (WBS 1.3.2.2.4)
    - Develop procedures
    - Software development
  - Beam studies (WBS 1.3.2.2.9)

Beam Based Alignment

Excite quad → Measure Response → Correct Orbit

We will be able to accomplish this because:

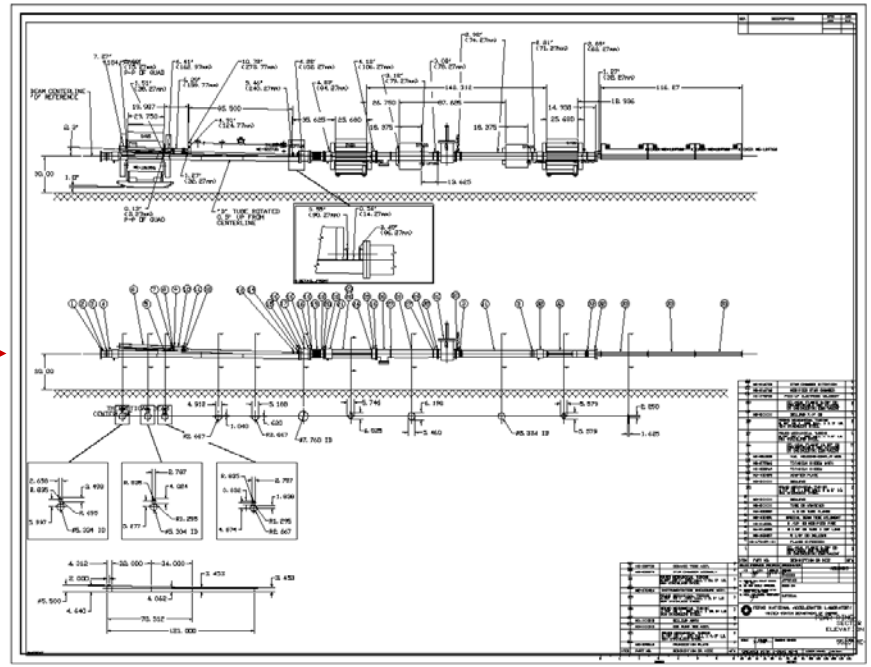
- Most quads have shunts installed
- New Upgraded BPMs in AP2 and the Debuncher
- New Greatly increased orbit correction capability in AP2 and the Debuncher

AP2 & Debuncher Acceptance -- Status (1)

Identification of limiting Apertures

- Documentation and Drawings
  - Debuncher injection region drawing complete
  - AP2 Physical Aperture table complete
  - Debuncher Physical Aperture table in process (complete by Fall 2003)
- Optical Survey

  Scheduled for Fall 2003 shutdown



Debuncher injection region drawing

AP2 & Debuncher Acceptance -- Status (2)

Mitigate Aperture Restrictions

- Most significant tasks:
  - Replace Debuncher quad D4Q4 with a large aperture quadrupole(s)
    Shutdown 2004
  - Vertically widen Band 4 stochastic cooling arrays
    Shutdown 2004
  - Move Debuncher RF cavities DRF2 and DRF3
    Shutdown 2004
- Other element modifications already identified (on WBS)
- Increase admittance of Debuncher injection channel (LBNL – Ina Reichel, Mike Zisman, John Corlett, and Massimo Placidi)
  - Review of Debuncher injection design – propose upgrades
  - Develop beam based alignment procedures
  - Status: Work started in April 2003. Presently collecting documentation and developing optics model and examining the effects of misalignments, strength errors, matching errors, and chromatic effects on the AP2 acceptance

AP2 & Debuncher Acceptance -- Status (3)

Implement Beam Based Alignment

- Instrumentation
  - AP2 BPMs
    - Presently unusable for reverse protons due to kicker ground surge
    - Relocation of BPM electronics – Est. Completion: Fall 2003
    - DAQ hardware & software upgrade – Est. completion: Fall 2004
  - Debuncher BPM upgrade
    - One sector (1/6) of new electronics is in place and is being tested
    - Remaining 5 sectors to be installed during Summer 2003 shutdown
    - Completion of software development expected by Fall 2003
    - Beam commissioning complete by mid 2004
- Orbit Control
  - AP2 line trim dipoles
    - 4 NDB dipole trims have been installed in the AP2 line during the past year
  - Install moveable stands for selected Debuncher quads
    - Cables were pulled during the January 2003 shutdown.
    - Install 10 stands in Fall 2003 shutdown
    - Install an additional 20 stands during the Summer 2004 shutdown
    - Expected Completion: Fall 2004

AP2 & Debuncher Acceptance -- Status (4)

- AP2 and Debuncher Lattice modeling
  - Working OptiM models of the AP2 line and the Debuncher exist
  - The models are being updated with alignment and physical aperture information as the data becomes available
  - LBNL investigating chromatic effects
- Beam Studies

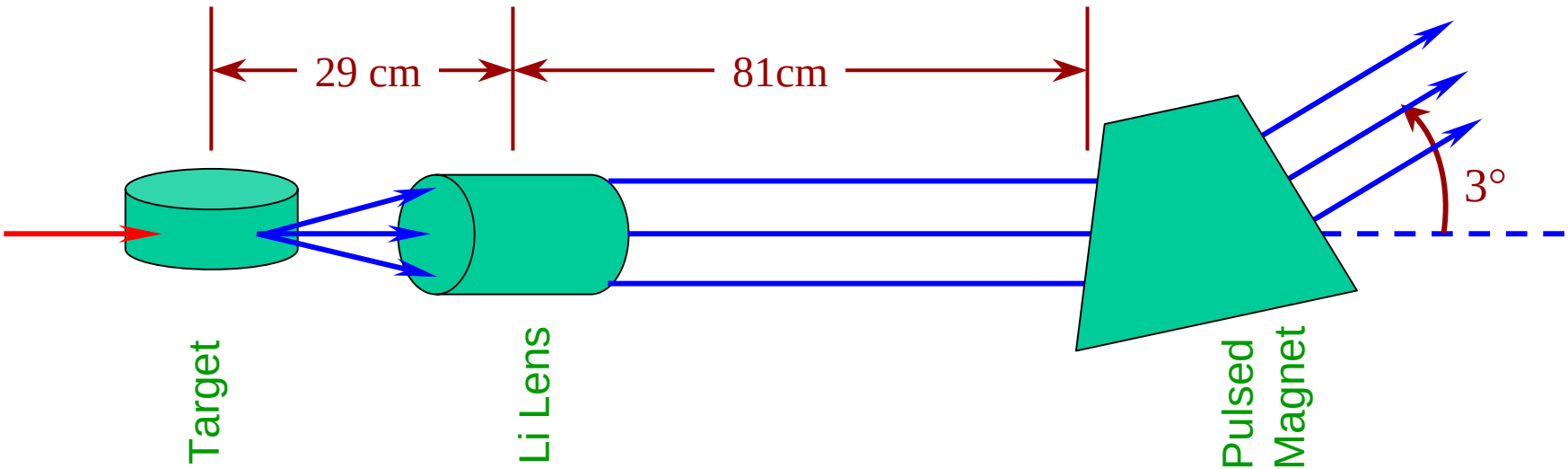
  Completed studies (Winter 2002-2003):
  - Reverse proton studies
    - Re-commission and develop various beam manipulation procedures (Debuncher, AP2, DRF3, DRF1) (40 hr)
    - Debuncher BPMs (Re-commission old electronics and prototype testing of new electronics) (8 hr)
    - Aperture measurements (4 hr)
  - Stacking studies
    - AP2 line orbit correction (12 hr)
    - Measure AP2 + Debuncher admittance (develop measurement techniques) (20 hr)
    - Measure AP2 + Debuncher momentum aperture (8 hr)

High Gradient Li Lens – Goals & Plan

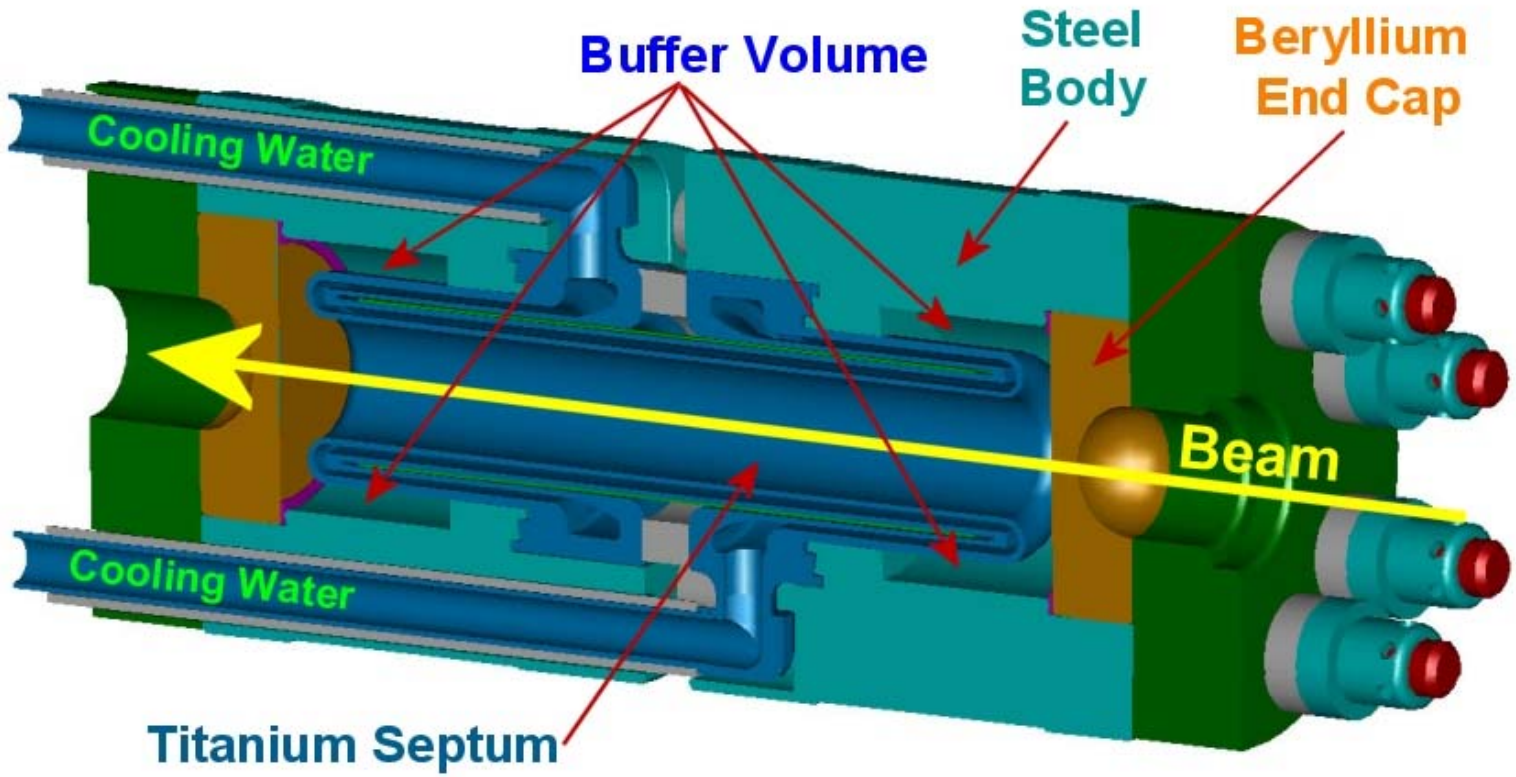
- **Goal**: Operate a Lithium lens --
  - at a gradient of at least 1000 T/m (34% ↑)
  - for at least 10 million pulses
- **Action Plan**
  - New solid Li Lens design (began 2000) (WBS 1.3.2.1.2)
  - General Li Lens R&D (WBS 1.3.2.1.3)
    - Autopsies of failed lenses
    - FEA model of present design
    - R&D of various Lens technologies
  - Improve present Li Lens design (WBS 1.3.2.1.1)
  - Fabricate New Lenses (WBS 1.3.2.1.5)

High Gradient Li Lens -- Parameters

	Present	Upgrade
Gradient	745 T/m	1000 T/m
Radius	1.0 cm	1.0 cm
Length	15 cm	15 cm
Lifetime	~9×10^6 pulses	10×10^6 pulses



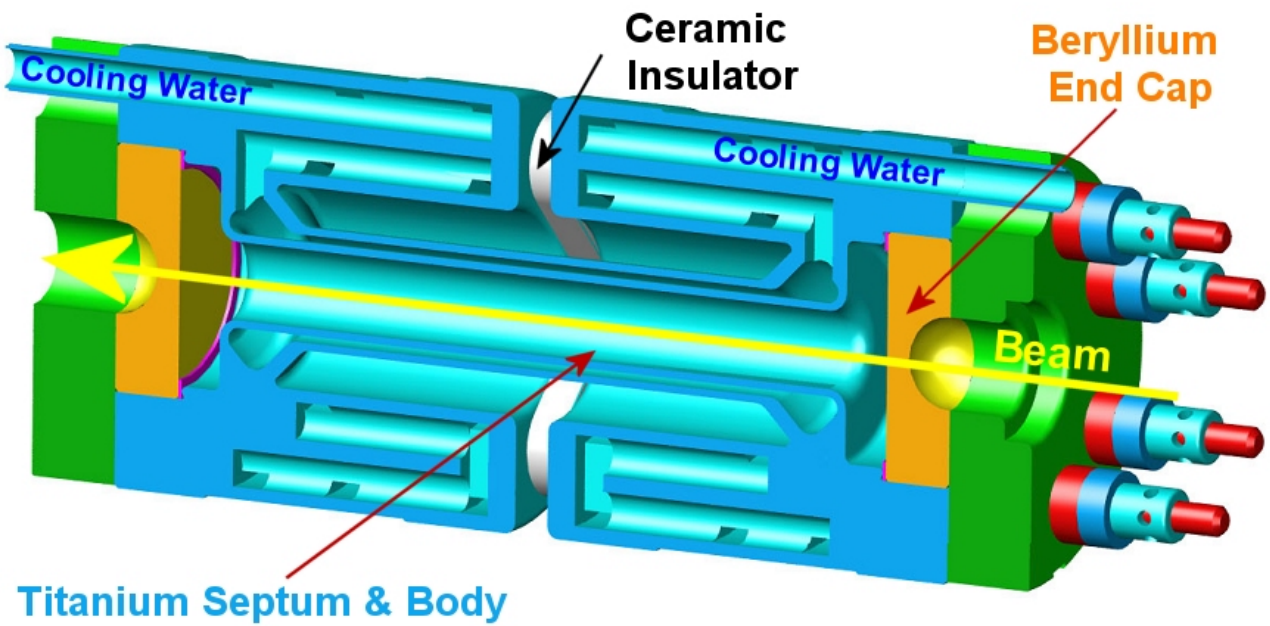
High Gradient Lithium Lens – Present Li Lens



High Gradient Lithium Lens – New Design

Features:

- Diffusion bonded titanium body
- Improved cooling
- Li buffer volumes eliminated



Diffusion Bonding:

- Better, more uniform cooling of lens body
- Allows use of new Ti alloy (Ti 10V-2Fe-3Al)
- Simplified lens fabrication
- Elimination of weld joints on septum

High Gradient Li Lens -- Status

- New Lens design
  - Complete and test new lens design prototype #1
    - Fill – Late July 2003
    - Begin testing on test stand by end of Summer 2003
- General Lens R&D
  - Lens #22 autopsy to start soon
    - 2nd longest lived lens (9.2 million pulses)
    - Did not fail during pulsing
  - Refine and expand FEA model
- Modifications to existing lens design
  - When present lens (Lens 24) fails, install a lens constructed with improved quality control procedures (Lens 28)
    - Lens 24 was installed in May 2003. Should last for ~1 year.
    - Operate 28 for 1 month at 745 T/m then increase to 820 T/m
- Fabrication of new lenses
  - Go into regular production of lenses with the new design
  - Construction of new design lenses scheduled to start in early 2005

Milestones & Cost Drivers

1.3.2	Pbar Acceptance	Steve Werkema	Date	
1.3.2.1.2.1.5	Prototype Lens 1: Completed (Milestone)	Pat Hurh	3/17/04	C
1.3.2.1.1.2.1	Decision on long lithium lens (Milestone)	Steve Werkema	3/17/04	B
1.3.2.1.4	**New Lens Operational (Milestone)**	**Jeff Spalding**	**4/11/05**	**A**
1.3.2.2.10	Initial AP2&DB Improvements Complete (Milestone)	Keith Gollwitzer	8/12/04	C
1.3.2.2.11	Intermediate AP2&DB Improvements Complete (Milesto	Keith Gollwitzer	8/10/05	C
1.3.2.2.12	**Final AP2&DB Improvements Complete (Milestone)**	**Jeff Spalding**	**12/4/06**	**A**

Major cost drivers:

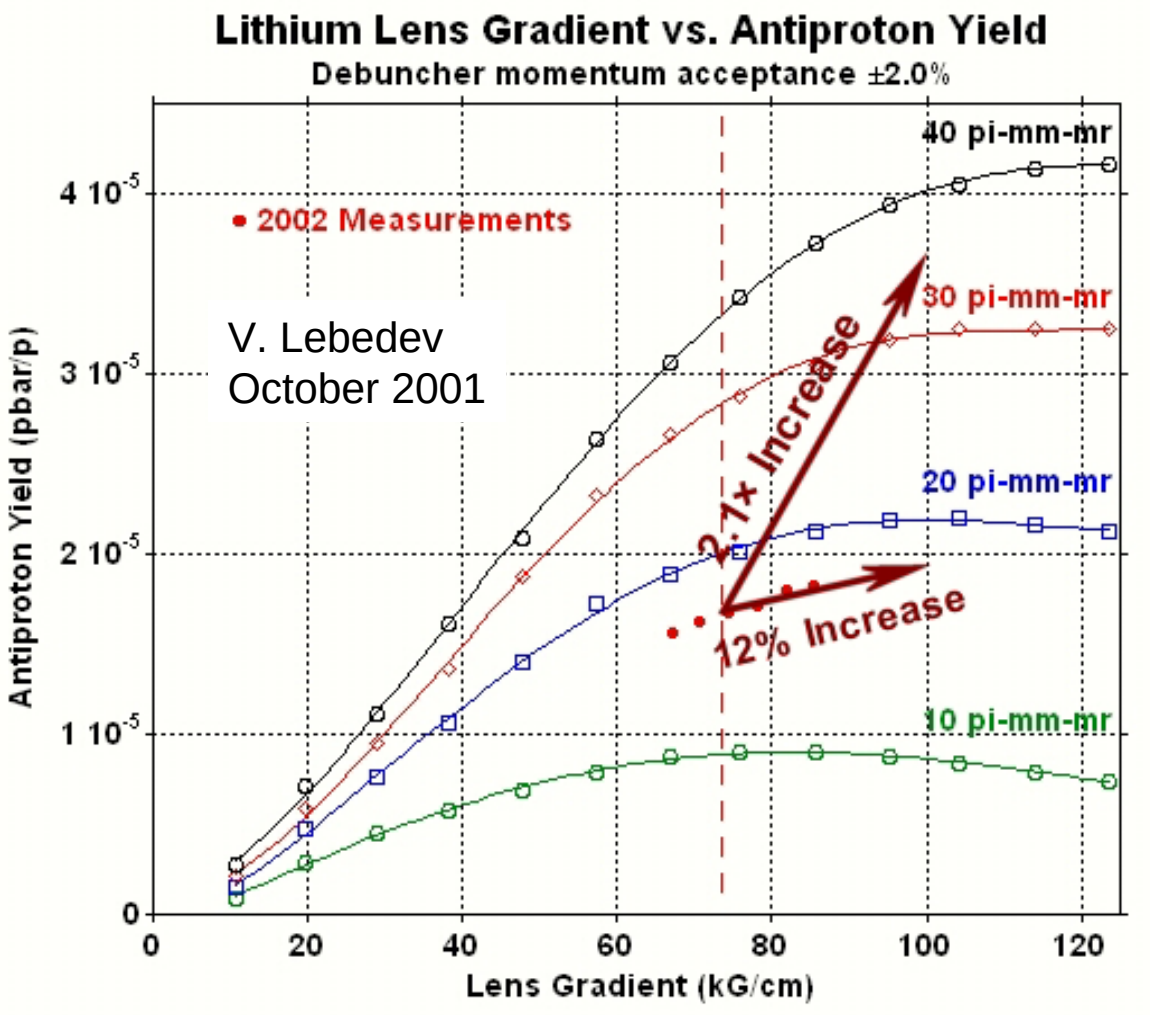
Li Lens Upgrades

- $200k – Contingency on the fabrication of 1st 4 operational lenses (new design)

AP2 & Debuncher Acceptance

- D4Q4 Magnet replacement ($115K) and injection septum rebuild ($200K) under WBS 1.3.2.2.5
- $500K – Mitigate yet to be determined aperture restrictions (WBS 1.3.2.2.5.3.4)
- $150K - "New" instrumentation under WBS 1.3.2.2.3.3
- $200K - Debuncher motorized quad stands under WBS 1.3.2.2.6

Conclusion – The Bottom Line



Present $\bar{p}$ yield:

16×10^{-6} $\bar{p}$/POT

Expected $\bar{p}$ yield:

36×10^{-6} $\bar{p}$/POT

$\Rightarrow$ **52×10^{10} $\bar{p}$/hr**

Delivered to the Accumulator for stacking

For:

8×10^{12} POT/pulse (slip stacking)

2.0 sec cycle time

Backup Slides

Backup Slides Follow

AP2 & Debuncher Acceptance – Beam Studies

Reverse Proton Studies

- Commission upgraded BPMs
- Measure Debuncher lattice – calibrate lattice model
- Commission orbit correction with motorized quad stands
- Center $\Delta p/p = 0$ beam in the quads
- Identify limiting apertures using loss monitors and one-bump scans

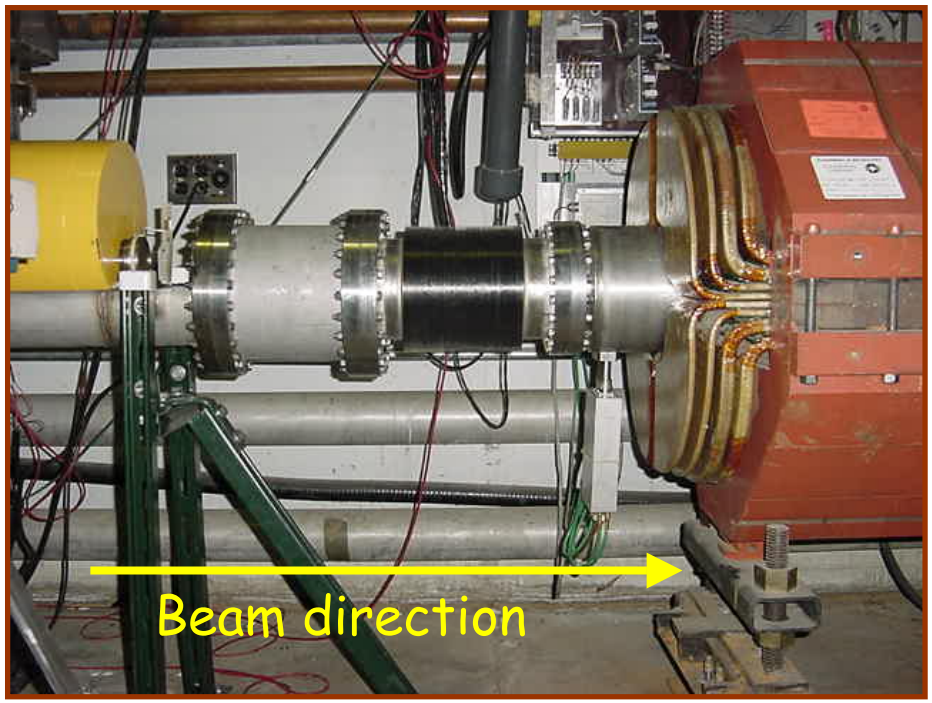
Stacking Studies

- Measure combined AP2 + Debuncher acceptance
- Use SEMS to center AP2 beam in quads

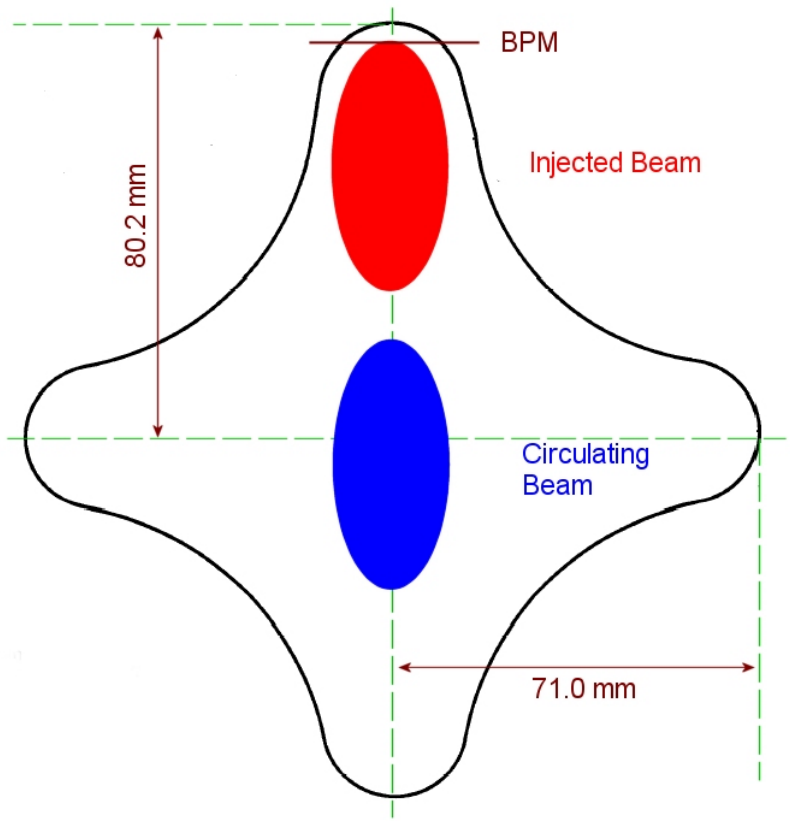
Forward Proton Studies

- AP2 Lattice measurements
- Center beam in quads

AP2 & Debuncher Acceptance – D4Q4 Replacement

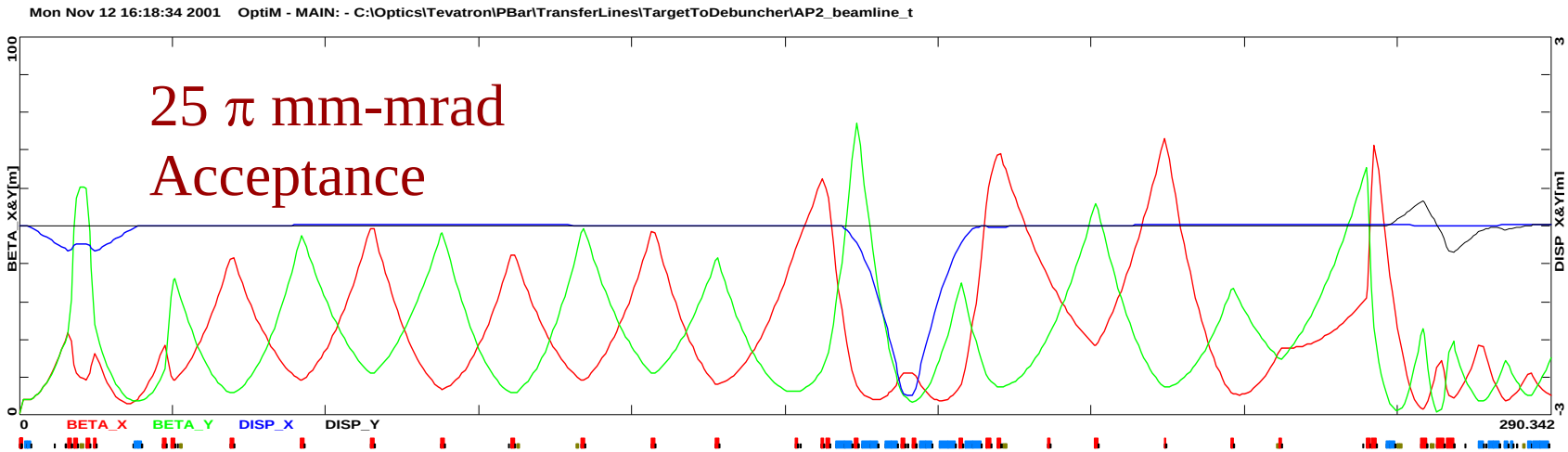


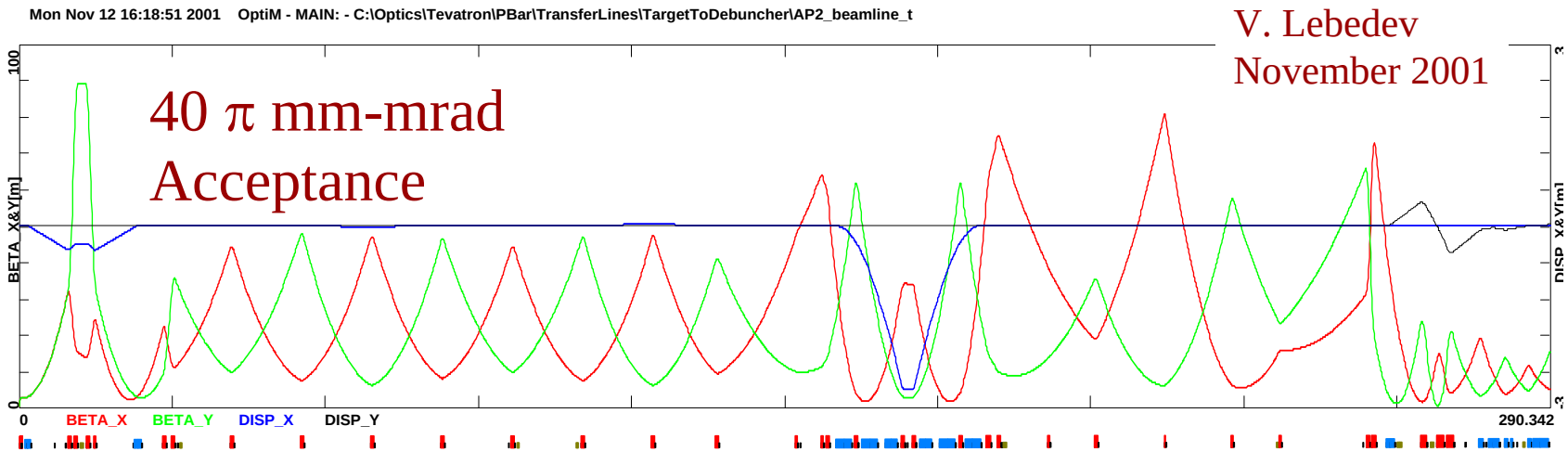
Debuncher injection. D4Q4 is on the right. Injected beam is in the upper portion of aperture, circulating beam is in the lower portion.



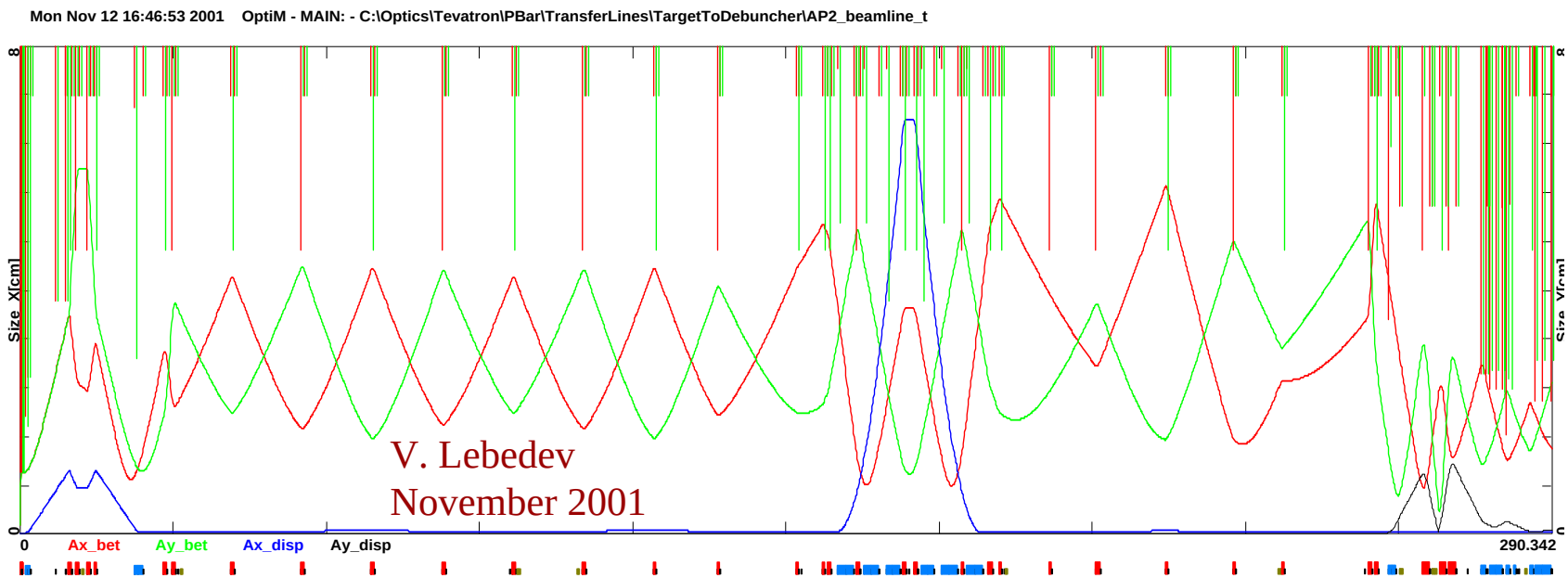
Emittance of injected and circulating beam is 40 π

AP2 & Debuncher Acceptance – AP2 Lattice





AP2 & Debuncher Acceptance – AP2 Aperture



Beam envelopes in AP2 line for an admittance of 40 π mm-mrad. Aperture limitations are shown by the vertical lines extending from the top of the plot. Synchrotron size is shown for an energy spread of ±2.5%.

The aperture information in this plot is incomplete and somewhat out of date. Updated information is being developed by the Tech. Div. Documentation and drawing survey.